APPLICATION FOR UNITED STATES LETTERS PATENT

of

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for

CARTRIDGE HAVING A POWER SOURCE AND ELECTRODE PAD, DEFIBRILLATOR HAVING A RECHARGEABLE BATTERY, DEFIBRILLATOR SYSTEM HAVING ONLY ONE REPLACEABLE COMPONENT, AND RELATED METHODS

File No. 10003975 (1727-28)

Certificate of Mailing Under 37 C.F.R. § 1.10

Express Mail Label No. ET564725108US Date of Deposit: November 5, 2001
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CARTRIDGE HAVING A POWER SOURCE AND ELECTRODE PAD, DEFIBRILLATOR HAVING A RECHARGEABLE BATTERY, DEFIBRILLATOR SYSTEM HAVING ONLY ONE REPLACEABLE COMPONENT, AND RELATED METHODS

FIELD OF THE INVENTION

[1] The invention relates generally to a medical device such as an automated or semi-automated external defibrillator (AED), and more particularly to a pad cartridge for storing a power source and an electrode pad, a defibrillator having a rechargeable battery, a defibrillator system having a single field-replaceable component, and related methods.

BACKGROUND OF THE INVENTION

[2] AEDs have saved many lives in non-hospital settings, and, as a result of advances in AED technology, the number of lives saved per year is rising. An AED is a battery-operated device that analyzes a patient's heart rhythm, and, if appropriate, administers an electrical shock (automated) or instructs an operator to administer an electrical shock (semi-automated) to the patient via electrode pads. For example, such a shock can often revive a patient who is experiencing ventricular fibrillation (VF).

[3] As discussed below in conjunction with **FIG. 1**, AEDs often require periodic maintenance by the customer, *i.e.,* "in the field". For example, one typically replaces the electrode pads after each use or after a specified period of nonuse, and replaces the battery when it is depleted.

[4] Unfortunately, AEDs often require different types of field maintenance at different intervals, and some types of field maintenance are relatively expensive. For example, the life of the electrode pads is typically unrelated to the life of the battery. Therefore, one typically replaces the pads and the battery at different times. Furthermore, because of the power requirements of an AED, a replacement battery is often relatively expensive.

[5] **FIG. 1** is a perspective view of a conventional AED system ***10***, which includes an AED ***12*** for generating a defibrillation shock, defibrillator electrode pads ***14a*** and ***14b*** for providing the shock to a patient (not shown), and a battery ***15***. A connector ***16*** couples the electrode pads ***14a*** and ***14b*** to a receptacle ***18*** of the AED ***12***. Typically, the electrode pads ***14a*** and ***14b*** are sealed within a flexible, *i.e.,* soft, package (not shown) that an operator (hands shown in **FIG. 1**) tears or peels open to access the electrode pads ***14a*** and ***14b***. The package acts as a moisture barrier that prevents the electrode-pad contact gel (not shown) from prematurely drying out during storage of the electrode pads ***14a*** and ***14b***. The battery ***15***, which typically is a lithium-ion battery, can provide relatively high power so that the AED ***12*** can quickly generate the defibrillation shock. The battery ***15*** and AED ***12*** may be stored separately, with the operator connecting the battery ***15*** to the AED ***12*** just prior to use in an emergency. Or preferably, the battery ***15*** and AED ***12*** may be stored together, with the battery ***15*** connected to the AED ***12*** during storage.

[6] The AED ***12*** includes a main on/off key switch ***22***, a display ***24*** for displaying operator instructions, cardiac waveforms, or other information, a speaker ***26*** for providing audible operator instructions or other information, an AED status indicator ***28***, and a shock button ***30***, which the operator presses to deliver a shock to the patient (not shown). The AED ***12*** may also include a microphone ***32*** for recording the operator's voice and other audible sounds that occur during the rescue, and a data card ***34*** for storing these sounds along with the patient's ECG and a record of AED events for later study.

[7] Still referring to **FIG. 1**, during an emergency where it is determined that the patient (not shown) may need a shock, the operator retrieves the AED ***12*** and installs the battery ***15*** if it is not already installed. Next, the operator removes the electrode pads ***14a*** and ***14b*** from the protective package (not shown) and inserts the connector ***16*** into the receptacle ***18***. Then, the operator turns the on/off switch ***22*** to the "on" position to activate the AED ***12***. Following the instructions displayed on the display ***24*** or "spoken" via the speaker ***26***, the operator places the electrode pads ***14a*** and ***14b*** on the patient in the respective positions shown in the pictures on the pads and on the AED ***12***. After the operator places the electrode

pads **14a** and **14b** on the patient, the AED **12** analyzes the patient's ECG to determine whether the patient is suffering from a shockable heart rhythm. If the AED **12** determines that the patient is suffering from a shockable heart rhythm, then it instructs the operator to depress the shock button **30** to deliver a shock to the patient. Conversely, if the AED **12** determines that the patient is not suffering from a shockable heart rhythm, it informs the operator to seek appropriate non-shock treatment for the patient and often disables the shock button **30** so that even if the operator presses the button **30**, the AED **12** does not shock the patient.

[8] The AED system **10** typically requires periodic field maintenance to ensure that it is ready for emergency use at all times. Specifically, one replaces the battery **15** when the AED **12** determines that the charge stored in the battery has fallen below a predetermined level. If the AED system **10** delivers no more than a few defibrillation shocks while a particular battery **15** is installed, then this battery usually lasts for approximately five years before leakage or power drawn by the AED **12** (*e.g.*, during periodic self-tests) drains the battery. Furthermore, one typically replaces the pads **14a** and **14b** after use — merely opening the pad package (not shown) typically constitutes use — or when they are no longer viable. For example, if the pads **14a** and **14b** are unopened, they usually have a shelf life of one to three years before the contact gel (not shown) dries out or the pads otherwise degrade from heat exposure or other causes.

[9] Unfortunately, because it is impractical to perform all of the field maintenance at the same time, one typically performs different aspects of the maintenance at different times. For example, if the AED system **10** is not used, then one typically replaces the pads **14a** and **14b** every one to three years and replaces the battery **15** every five years. Although one could eliminate separately replacing the battery **15** by prematurely replacing the battery whenever he/she replaces the pads **14a** and **14b**, the high cost (approximately $80 - $100) of the battery **15** makes this impractical.

[10] Consequently, a need exists for an AED system that makes it more practical to perform different aspects of the field maintenance at the same time. Furthermore, a need exists for an AED system that allows one to perform different

aspects of the field maintenance by replacing a single component. In addition, a need exists for an AED system that reduces the cost of maintenance.

SUMMARY OF THE INVENTION

[11] In one embodiment of the invention, a defibrillator system includes a defibrillator and a cartridge attachable to the defibrillator. The cartridge includes an electrode pad and a power source such as a battery, which may recharge a defibrillator battery, power defibrillator circuitry, or both.

[12] Because the cartridge includes both a power source and an electrode pad, one can replace the power source and the pad at the same time by replacing a single cartridge. Furthermore, in defibrillator systems where the power source charges the defibrillator battery, the power source can be selected to have approximately the same life as the pad, thus making it practical to replace the power source and pad at the same time. In addition, maintenance for such a charging defibrillator system typically costs less than for a non-charging defibrillator system because it is often less expensive to replace the power source than to replace the defibrillator battery.

BRIEF DESCRIPTION OF THE DRAWINGS

[13] **FIG. 1** is a perspective view of a conventional AED system.

[14] **FIG. 2** is a perspective view of an AED system having a pad/power-source cartridge and a rechargeable AED according to an embodiment of the invention.

[15] **FIG. 3** is a perspective view of an AED system having a pad/power-source cartridge and a non-rechargeable AED according to an embodiment of the invention.

[16] **FIG. 4** is a perspective view of an AED system having a pad cartridge and a rechargeable AED according to an embodiment of the invention.

[17] **FIG. 5** is a perspective view of a pad/power-source cartridge having multiple compartments and multiple connectors according to an embodiment of the invention.

[18] FIG. **6** is a block diagram of an AED circuit that the AEDs of **FIGS. 2 – 4** can incorporate according to an embodiment of the invention.

[19] **FIG. 7** is a block diagram of the battery charger of **FIG. 6** according to an embodiment of the invention.

[20] **FIG. 8** is a diagram of a fuel cell that can be used in place of one or more batteries of **FIGS. 2 – 5** according to an embodiment of the invention.

[21] **FIG. 9** is a diagram of a fuel-cell system that includes the fuel cell of **FIG, 8** according to an embodiment of the invention.

[22] **FIG. 10** is a diagram of a fuel-cell system that includes the fuel cell of **FIG, 8** according to another embodiment of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[23] The following discussion is presented to enable a person skilled in the art to make and use the invention. Various modifications to the embodiments will be readily apparent to those skilled in the art, and the generic principles herein may be applied to other embodiments and applications without departing from the spirit and scope of the present invention as defined by the appended claims. Thus, the present invention is not intended to be limited to the embodiments shown, but is to be accorded the widest scope consistent with the principles and features disclosed herein. Furthermore, for purposes of the application, "a self-contained power source" is a power source, such as a battery, fuel cell, or solar cell, that can provide power without a connection to power mains such as an AC outlet.

[24] **FIG. 2** is a perspective view of an AED system ***36*** that includes an AED ***38*** and a pad/power-source cartridge ***40*** according to an embodiment of the invention, where like numerals in **FIGS. 1** and **2** refer to like elements in the systems ***10*** and ***36***. The AED ***38*** includes a rechargeable defibrillator battery ***42***, and the cartridge ***40*** includes a self-contained power source, here a battery ***44***, that charges the battery ***42***. Consequently, one need only replace the cartridge ***40*** for routine field maintenance. Furthermore, the cost of this maintenance is often reduced because the battery ***44*** is typically much less expensive than the defibrillator battery ***42***.

[25] The AED ***38*** includes the rechargeable battery ***42***, a connector ***46***, a receptacle ***48*** for receiving the cartridge ***40***, and other features discussed above in conjunction with **FIG. 1**.

[26] The battery ***42*** charges the AED's shock circuitry (**FIG. 6**) when the AED ***38*** determines that a patient (not shown) requires a shock, and also powers the remaining circuitry during treatment of the patient and during periodic self tests of the AED. To charge the shock circuitry relatively quickly — typically within a few seconds — the battery ***42*** should be able to generate a relatively high charging current. Furthermore, to power the AED during periodic self tests over a relatively long period of time — typically 3 – 5 years or more — the battery ***42*** should have relatively low leakage and have a relatively long life. Moreover, to reduce maintenance costs, the battery ***42*** should be rechargeable. Consequently, the battery ***42*** is typically a lithium-ion battery, although the battery ***42*** may be a nickel-cadmium or other type of battery that has the desired characteristics. Although shown disposed within the AED ***38***, the battery ***42*** may be disposed outside of the AED as shown in **FIG. 1**. In addition, although the battery ***42*** may be field replaceable, one typically sends the AED ***38*** back to the manufacture for replacement of the battery ***42***, or discards the AED, when the battery ***42*** can no longer hold a charge. Moreover, although on battery ***42*** is shown, the AED ***38*** may include multiple batteries ***42***.

[27] Regarding the connector ***46*** and the receptacle ***48***, similar connectors and receptacles, as well as other techniques for attaching the cartridge ***40*** to the AED ***38***, are discussed in U.S. Patent App. Ser. No. 09/852,431, entitled CARTRIDGE FOR STORING AN ELECTRODE PAD AND METHODS FOR USING AND MAKING THE CARTRIDGE, which is incorporated by reference.

[28] And although shown as lacking the on/off switch ***22*** and display ***24***, the AED ***38*** may include these features. But, to accommodate the connector ***46*** and receptacle ***48***, the switch ***22*** and the display ***24*** may be displaced from their respective locations on the AED ***12*** of **FIG. 1**.

[29] Still referring to **FIG. 2**, the cartridge ***40*** includes a compartment ***50*** for storing the electrode pads ***14a*** and ***14b*** and the charging battery ***44***, a lidded housing

52 that defines the compartment ***50***, a connector ***54*** that mates with the connector ***46*** when the housing ***52*** is disposed within the receptacle ***48***, and leads ***56a*** and ***56b*** that connect the battery ***44*** to the connector ***54***. In one embodiment, the battery ***44*** is a low-cost disposable battery such as a zinc-carbon, zinc-mercury, or zinc-manganese, *i.e.,* alkaline, battery. Such a battery typically stores a relatively high amount of energy when fresh and costs less than $1.00 (U.S.). Although the battery ***44*** may be unable to generate a current high enough to charge the shock circuitry (**FIG. 6**) of the AED ***38***, it can recharge the battery ***42***. Furthermore, low-cost disposable batteries, particular alkaline batteries, have been found to have approximately the same shelf life as the pads ***14a*** and ***14b*** and to degrade with temperature at a rate that is similar to the pads' temperature-degradation rate. The battery ***44*** is coupled to the battery ***42*** via the connectors ***46*** and ***54***, and is conventionally secured within the compartment ***50***. Furthermore, the battery ***44*** may or may not be replaceable independently of the cartridge ***40***, and although one battery ***44*** is shown, the cartridge may store multiple batteries ***44*** coupled in either series or parallel. The housing ***52*** is typically formed from plastic and is hermetically sealed with the pads ***14a*** and ***14b*** and battery ***44*** inside. In addition, although the cartridge ***40*** is shown storing a pair of electrode pads ***14a*** and ***14b*** and storing the battery ***44*** inside the housing ***52***, the cartridge ***40*** may include more or fewer pads and store the battery outside the housing. Cartridges similar to the cartridge ***40*** (except without the battery ***44***) are discussed in U.S. Patent App. Ser. No. 09/852,431, entitled CARTRIDGE FOR STORING AN ELECTRODE PAD AND METHODS FOR USING AND MAKING THE CARTRIDGE, which is incorporated by reference.

[30] In operation, one periodically replaces a single component — the cartridge ***40*** — in the field to maintain the AED system ***36***. That is, one replaces the cartridge ***40*** at regular intervals to maintain a viable set of pads ***14a*** and ***14b*** and an adequate charge level on the defibrillator battery ***42***. Therefore, by allowing routine field maintenance with the replacement of a single component, the AED system ***36*** is relatively simple to maintain. Furthermore, because, as discussed above, the battery ***44*** typically costs on the order of 1/100th of what the battery ***42*** costs, including the

battery ***44*** in the cartridge ***40*** reduces the cost of maintaining the system ***36***. Moreover, although the replacement cartridge ***40*** includes the battery ***44***, the original cartridge ***40*** that comes with the AED system ***36*** may omit the battery ***44*** because the defibrillator battery ***42*** is fresh and typically has an expected life that is at least as long as the shelf life of the pads ***14a*** and ***14b***.

[31] In one embodiment, one replaces the original cartridge with a replacement cartridge ***40*** when the pads ***14a*** and ***14b*** need replacement either because they have been used or because their shelf life has expired. Once the replacement cartridge ***40*** is installed in the AED ***38***, the battery ***44*** recharges the battery ***42*** to a predetermined charge level, and thereafter maintains this charge level on the battery ***42*** until the battery ***44*** can no longer do so. As long as the battery ***44*** has a life that is at least as long as the pads' shelf life, one will typically replace the cartridge ***40*** before the battery ***44*** loses its ability to charge the battery ***42***.

[32] In another embodiment, one replaces the original cartridge with a replacement cartridge ***40*** when the battery ***44*** needs replacement. Specifically, the AED ***38*** monitors the battery ***44*** and sounds a warning (*e.g.,* via the speaker ***26***) when the charge level on the battery ***44*** falls below a predetermined threshold. As long as the pads ***14a*** and ***14b*** have a life that is at least as long as the battery's expected life, then one will typically replace the cartridge ***40*** before the pads expire. Furthermore, as stated above, some types of batteries such as alkaline batteries degrade with exposure to heat at a rate similar to the rate at which the pads ***14a*** and ***14b*** degrade with exposure to heat. Therefore, by using such a battery for the battery ***44***, the AED ***38*** can sound a warning if one should replace the cartridge ***40*** earlier than scheduled due to heat degradation of the pads ***14a*** and ***14b***.

[33] In yet another embodiment, one replaces the original cartridge with a replacement cartridge ***40*** when the battery ***42*** needs recharging. Specifically, the AED ***38*** monitors the battery ***42*** and sounds a warning (*e.g.,* via the speaker ***26***) when the charge level on the battery ***42*** falls below a predetermined threshold. This indicates that the battery ***44*** needs to be replaced because it can no longer charge the battery ***42***. A potential advantage to monitoring the battery ***42*** instead of the

battery ***44*** is a longer time between replacements of the cartridge ***40*** because the battery ***44*** will often discharge before the battery ***42***.

[34] Still referring to **FIG. 2**, one or more fuel-cell systems (**FIGS. 9-10**) may be used in place of the battery ***42***. A fuel-cell system typically includes a fuel cell (**FIG.8**) and a fuel reservoir connected to the cell. In one embodiment, the fuel cell is located in the AED ***38*** and the cartridge ***40*** contains the reservoir. The fuel cell uses this fuel to generate the electricity that charges the battery ***44***. When the fuel is or nearly is exhausted, one replaces the cartridge ***40*** to replenish the fuel supply. In another embodiment, both the fuel cell and the fuel reservoir are located in the cartridge ***40***.

[35] **FIG. 3** is a perspective view of an AED system ***60*** that includes an AED ***62*** and a pad/power-source cartridge ***64*** according to an embodiment of the invention, where like numerals in **FIGS. 2** and **3** refer to like elements in the systems ***36*** and ***60***. A major difference between the AED systems ***36*** and ***60*** is that in the system ***60***, the AED ***62*** has no battery, and a battery ***66*** or other power source in the cartridge ***64*** powers the AED ***62***. The battery ***66*** is similar to the battery ***42*** of **FIG. 2** so that it can charge the shock circuitry (**FIG. 6**) relatively quickly and power the AED ***62*** during periodic self tests over a relatively long period of time, which is typically at least the shelf life of the pads ***14a*** and ***14b***. Although the high cost of the battery ***66*** makes replacing the cartridge ***64*** more expensive than changing the cartridge ***40*** of **FIG. 2**, one does not have the added task of replacing a defibrillator battery, such as the battery ***42*** of **FIG. 2**, or discarding the AED when the defibrillator battery can no longer hold a charge. Furthermore, like the AED system ***36*** of **FIG. 2**, the AED system ***60*** has only one field-replaceable component, the cartridge ***62***. Moreover, although only one battery ***66*** is shown, the cartridge ***64*** may include multiple batteries ***66***.

[36] Alternatively, one or more fuel-cell systems (**FIGS. 9 – 10**) may be used in place of the battery ***66***. The fuel cell (**FIG. 8**) and its fuel reservoir (**FIGS. 9 – 10**) may be located in the cartridge ***64***, or the cell may be located in the AED ***62*** and the reservoir located in the cartridge ***64***.

[37] **FIG. 4** is a perspective view of an AED system ***70*** that includes an AED ***72*** and a pad cartridge ***74*** according to an embodiment of the invention, where like numerals in **FIGS. 2** and **4** refer to like elements in the systems ***36*** and ***70***. A major difference between the AED systems ***36*** and ***70*** is that in the system ***70***, a recharge battery ***76***, which is similar to the battery ***44*** of **FIG. 2**, is disposed in the AED ***72***, not in the cartridge ***74***. Although locating the recharge battery ***76*** away from the cartridge ***74*** separates replacement of the pads ***14a*** and ***14b*** and the recharge battery into two maintenance steps, the battery ***76*** reduces maintenance costs because it is less expensive to replace than the defibrillator battery ***42*** as discussed above in conjunction with **FIG. 2**. Furthermore, if the battery ***76*** and pads ***14a*** and ***14b*** do not have similar lives, maintenance costs are further reduced because one need not replace viable pads ***14a*** and ***14b*** just because the battery ***76*** needs replacing or vice versa.

[38] The AED ***72*** includes the rechargeable defibrillator battery ***42***, recharge battery ***76***, a connector ***78***, the receptacle ***48*** for receiving the cartridge ***74***, a compartment ***80*** for the battery ***76***, and other features discussed above in conjunction with **FIG. 1**. As discussed above, the battery ***76*** is similar to the battery ***44*** of **FIG. 2**. And, if the battery ***76*** is of the appropriate chemistry and the AED ***38*** and pads ***14a*** and ***14b*** are stored together, the AED can detect temperature degradation of the pads by monitoring the battery ***76*** as discussed above in conjunction with **FIG. 2**. The connector ***78*** is similar to the connector ***46*** of **FIG. 2** except that it does not couple a recharge battery to the defibrillator battery ***42***. The battery compartment ***80*** can have a cover (not shown) and otherwise be similar to conventional battery compartments present in battery-operated electronic devices such as portable compact-disc (CD) players (not shown). Furthermore, although shown disposed within the AED ***72*** and designed to hold only one battery ***76***, the compartment ***80*** may be attached to the outside of the AED or may be designed to hold multiple batteries ***76*** in a serial or parallel configuration.

[39] The cartridge ***74*** includes a connector ***82***, and, except for not storing a recharge battery, is otherwise similar to the cartridge ***40*** of **FIG. 2**. The connector ***82***

is similar to the connector **54** of **FIG. 2** except that it does not couple a recharge battery to the defibrillator battery **42**.

[40] Still referring to **FIG. 4**, one or more fuel-cell systems (**FIGS. 9-10**) may be used in place of the battery **76**. When the fuel cell's fuel is or nearly is exhausted, one refills the fuel reservoir or replaces the entire fuel-cell system.

[41] Alternatively, the battery **76** can be eliminated, and one or more fuel-cell systems (**FIGS. 9-10**) can be used in place of the battery **42**. When the cell's fuel is or nearly is exhausted, one replaces the fuel-cell system. Alternatively, one can merely refill the fuel reservoir. Furthermore, if the fuel reservoir is large enough, the fuel cell can power the AED **72** almost indefinitely.

[42] **FIG. 5** is a perspective view of a cartridge **90** that may replace the cartridges **40** and **64** in the AED systems **36** and **60** of **FIGS. 2** and **3**, respectively, according to an embodiment of the invention, where like numerals refer to like elements of the cartridges **40**, **64**, and **90**. A major difference between the cartridge **90** and cartridges **40** and **64** is that the cartridge **90** includes pad and battery compartments **92** and **94**, which are separated by a divider **96**, and includes separate pad and battery connectors **98** and **100**. A battery **102** is disposed in the battery compartment **94**, and may be similar to the battery **44** of **FIG. 2** in that it charges a defibrillator battery, or may be similar to the battery **66** of **FIG. 3** in that it powers the AED **62**. Although one battery **102** is shown, the battery compartment **94** may be designed to hold multiple batteries **102** in a series or parallel configuration. Furthermore, one may use one or more fuel-cell systems (**FIGS. 9-10**) in place of the battery **102**.

[43] Referring to **FIGS. 2**, **3**, and **5**, to accommodate the connectors **98** and **100** of the cartridge **90**, each of the AEDs **38** and **62** would be modified to include two corresponding connectors instead of one connector **46** and **56**, respectively. Otherwise, the AEDs **38** and **62** would be the same as discussed above in conjunction with **FIGS. 2** and **3**, respectively.

[44] **FIG. 6** is a block diagram of an AED circuit **110**, which the AED's **38**, **62**, and **72** of **FIGS. 2 – 4**, respectively, can incorporate according to an embodiment

of the invention. For clarity, the circuit ***110*** is discussed in conjunction with the AED ***38***, it being understood that the discussion also applies to the circuit ***110*** when used in the AEDs ***62*** and ***72*** unless otherwise noted.

[45] The AED circuit ***110*** includes a power management (PM) circuit ***112***, which interfaces with a processing unit (PU) ***114*** via a gate array ***116***, a shock-delivery-and-ECG-front-end circuit ***118***, the defibrillator battery ***42***, (which powers the circuit ***110***), and a recharge battery ***44*** (except no recharge battery in the AED ***62***). Under the control of the PU ***114***, the PM circuit ***112*** distributes power from the battery ***42*** to the other circuits of the circuit ***110***, and includes a battery charger ***117*** for charging the battery ***42*** with power from the battery ***44***. The battery charger ***117*** is further discussed below in conjunction with **FIG. 7**, and may be omitted from the AED ***62*** (**FIG. 3**) because there is no recharge battery ***44***. In addition, the PU ***114*** monitors the voltage across the battery ***44*** via the PM ***112*** and generates an alarm via the display ***24***, speaker ***26***, or other means to indicate that the battery ***44***, and thus the cartridge ***40*** (**FIG. 2**), needs to be replaced. Furthermore, although shown as disposed in the cartridge ***40*** (**FIG. 2**), the battery ***44*** may be disposed within the AED as shown for the AED ***72*** of **FIG. 4**.

[46] The AED circuit ***110*** also includes the shock-delivery-and-ECG-front-end circuit ***118***, which, during treatment of a patient (not shown), samples the patient's ECG to determine if the patient is suffering from a shockable heart arrhythmia. The PU ***114*** receives the samples from the circuit ***118*** via a gate array ***120*** and analyzes them. If analysis indicates that the patient is suffering from a shockable heart rhythm, then the PU ***114*** instructs the circuit ***118*** via the gate array ***120*** to enable delivery of a shock to the patient when an operator (not shown) presses the shock button ***30***. Conversely, if analysis indicates that the patient is not suffering from a shockable heart rhythm, then the PU ***114*** effectively disables the shock button ***30*** by preventing the circuit ***118*** from delivering a shock to the patient when the operator presses the shock button ***30***.

[47] Still referring to **FIG. 6**, the on/off switch ***22*** (**FIG. 1**) turns the AED circuit ***110*** "on" and "off" and the gate array ***116*** interfaces the PM circuit ***112***, the

on/off switch ***22***, and the status indicator ***28*** to the shock-delivery-and-ECG-front-end circuit ***118***, the PU ***114***, and the gate array ***120***.

[48] The circuit ***110*** also includes the display ***24***, which presents information to an operator, the speaker ***26***, which may provide audio instructions to the operator, and the microphone ***32***, which may record the operator's voice and other audible sounds. The data card ***32*** is connected to the gate array ***120*** via a port ***122***, and may store the operator's voice and other sounds along with the patient's ECG and a record of AED events for later study.

[49] A status-measurement circuit ***124*** provides the status of the other circuits of the AED circuit ***110*** to the PU ***114***, and LEDs ***126*** and the status indicator ***28*** provide information to the operator (not shown in **FIG. 6**) such as whether the PU ***114*** has enabled the shock-delivery-and-ECG-front-end circuit ***118*** to deliver a shock to the patient (not shown) or when the recharge battery ***44*** needs to be replaced. A contrast button ***128*** allows the operator to control the contrast of the display screen ***24*** if present, and a memory such as a read only memory (ROM) ***130*** stores programming information for the PU ***114*** and the gate arrays ***116*** and ***120***.

[50] The AED circuit ***110*** and other similar AED circuits that may incorporate the PM circuit ***112*** are discussed in the following references, which are incorporated by reference: U.S. Patent No. 5,836,993, U.S. Patent No. 5,735,879 entitled ELECTROTHERAPY METHOD AND APPARATUS, U.S. Patent No. 5,607,454 entitled ELECTROTHERAPY METHOD AND APPARATUS, and U.S. Patent No. 5,879,374 entitled DEFIBRILLATOR WITH SELF-TEST FEATURES.

[51] **FIG. 7** is a block diagram of the battery charger ***117*** of **FIG. 6** according to an embodiment of the invention, and of other circuits and components of the circuit ***110*** that interact with the charger. The charger ***117*** includes a voltage booster ***140***, a supply circuit ***142*** for powering the charger ***117*** and other circuits of the circuit ***110*** during charging of the battery ***42***, a battery selector ***144*** for selecting the battery — recharge or defibrillator — to power the supply circuit ***142***, and a charge circuit ***146*** for charging the battery ***42***. There are many conventional designs for the booster ***140***, supply circuit ***142***, selector ***144***, and charge circuit ***146*** that are suitable for use

in the battery charger ***117***. Therefore, detailed discussions of these circuits are omitted for brevity.

[52] In operation, the battery charger ***117*** uses the recharge battery ***44*** to maintain a predetermined charge level on the defibrillator battery ***42***. Specifically, the PU ***114*** monitors the voltage across the defibrillator battery ***42*** via the gate array ***116***. If this voltage is below a recharge level, for example 3.5 volts (V), then the PU ***114*** activates the charge circuit ***146*** to charge the defibrillator battery ***42*** with energy from the recharge battery ***44***. When the voltage across the defibrillator battery ***42*** surpasses a charged level, for example 3.9 V, the PU ***114*** deactivates the charge circuit ***146***. The PU ***114*** also monitors the voltage across the recharge battery ***44*** via the gate array ***116***, and, as discussed above in conjunction with **FIGS. 2** and **6**, generates an alarm signal to indicate that the battery ***44*** needs to be replaced if this voltage is below a predetermined level.

[53] The battery selector ***144*** connects the recharge battery ***44*** to circuits that are needed during the recharge operation if the voltage across the defibrillator battery ***42*** is too low to power these circuits. As stated above, the PU ***114*** monitors the voltage across the defibrillator battery ***42***. If this voltage falls below a low-power level, for example 3.3 V, then the PU ***114*** causes the battery selector ***144*** to couple the recharge battery ***44*** to the supply circuit ***142***. When the voltage increases above the low-power level, the PU ***114*** causes the battery selector ***144*** to couple the defibrillator battery ***42*** to the supply circuit ***142***. Such a low-power situation may occur if the recharge battery ***44*** is depleted and is not replaced soon enough to maintain an adequate charge on the defibrillator battery ***42***. Without the battery selector ***144***, such a situation would render the battery recharger ***117*** inoperable until the defibrillator battery ***42*** was replaced. Consequently, the battery selector ***144*** avoids this inconvenience by powering the battery recharger ***117***, the PU ***114***, and other circuits with the recharge battery ***44*** until the voltage across the defibrillator battery ***42*** is high enough to power these circuits.

[54] The voltage booster ***140*** boosts the voltage across the recharge battery ***44*** to a level that is high enough to charge the defibrillator battery ***42***. For example, if the recharge battery ***44*** is a 1.5 V AA battery, then the booster ***140*** may boost the 1.5

V to 4.5 V so that the charge circuit ***146*** can charge the battery ***42*** to 3.9 V. But if the voltage across the recharge battery ***44*** is high enough to charge the defibrillator battery ***42***, then the booster ***140*** may be omitted. Moreover, if the voltage across the defibrillator battery ***42*** is too high, then one may replace the booster ***140*** with a down converter (not shown) to reduce the voltage to a level suitable for charging the defibrillator battery ***42***.

[55] **FIG. 8** is a diagram of a fuel cell ***160*** of a fuel-cell system (**FIGS. 9-10**) that can be used in place of one or more of the batteries ***42*** and ***44*** (**FIG. 2**), ***66*** (**FIG. 3**), ***42*** and ***76*** (**FIG. 4**), and ***102*** (**FIG. 5**) as discussed above in conjunction with **FIGS. 2 – 5**. The fuel cell ***160*** combines a fuel, such as methane, hydrogen gas, or methanol, with an oxidant to generate electric power. The cell ***160*** includes an anode ***162*** (+) and a cathode ***164*** (-) and a proton-exchange membrane ***166*** that allows the fuel and oxidant — the oxidant is typically oxygen from the air, although pure oxygen or other oxidants can be used — to combine and generate voltage V across the anode and cathode. Intakes ***168*** and ***170*** respectively provide the oxygen and fuel to respective sides of the membrane ***166***, and a vent ***172*** allows the byproducts — typically water — of the fuel and oxygen to escape from the interior of the cell ***160***. When a load ***174*** is connected between the terminals ***176*** and ***178***, a current flows from the anode ***162***, through the load ***174***, to the cathode ***164***.

[56] **FIG. 9** is a diagram of a fuel-cell system ***180*** that includes the fuel cell ***160*** of **FIG. 8**. The system ***180*** includes a fuel reservoir ***182*** that is remote from the cell ***160*** and a connector ***184*** for coupling the reservoir's outlet ***186*** to the cell's fuel intake ***170***. The system ***180*** can be used in conjunction with the AED system ***36*** (**FIG. 2**), where the cell ***160*** is located in the AED ***38*** and the reservoir ***182*** is located in the cartridge ***42***.

[57] **FIG. 10** is a diagram of a fuel-cell system ***190*** that includes the fuel cell ***160*** of **FIG. 8**. The system ***190*** includes a fuel reservoir ***182*** that is connected to or integrated with the cell ***160***. The reservoir's outlet ***192*** is integral with the cell's fuel intake ***170*** or is connected thereto with a connector (not shown in **FIG. 10**). The system ***190*** can be used in conjunction with the AED system ***60*** (**FIG. 3**), where the system ***190*** is located in the cartridge ***64***. Alternatively, the system ***190*** can be used

in conjunction with the AED system ***70*** (***FIG. 4***), where the system ***190*** is located in the AED ***72***.